US ICF/IFE Overview and Tritium Implications

R. Scott Willms and Art Nobile, Los Alamos National Lab
Tom Bernat and Mark Mintz, Lawrence Livermore National Lab
Dan Goodin and Chuck Gibson, General Atomics
David Harding, University of Rochester

Presented at the 6th International Conference
on Tritium Science and Technology
November 11-16, 2001
Tsukuba, Japan

LA-UR 01-6245

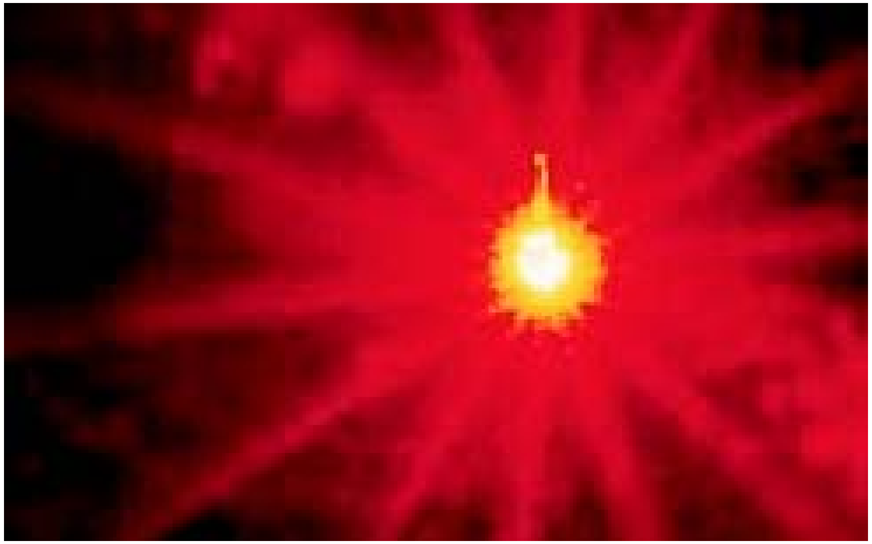
Contributors

Gerry Kulcinski, U. of Wisconsin
Wayne Meier, LLNL
John Sethian, NRL
Ralph Moir, LLNL
Roger Janezic, LLE
Mike Sorem, LANL
Jim Anderson, NNSA
Steve Batha, LANL
Grant Logan, LLNL/LBNL
Dave Petti, INEEL

Talk Outline

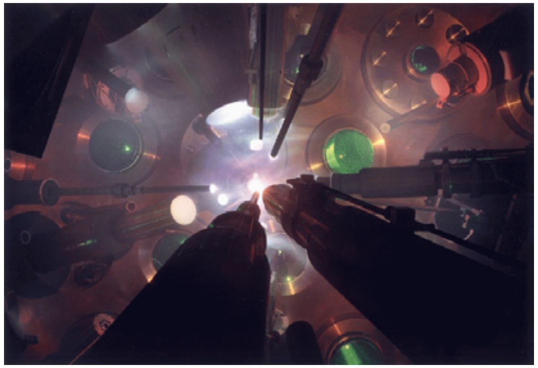
- ICF/IFE overview
- Inertial fusion target overview
- ICF
  - Omega Laser
    - Overview
    - Tritium issues
  - National Ignition Facility
    - Overview
    - Tritium issues
- IFE
  - Program overview
  - Tritium issues

ICF/IFE overview

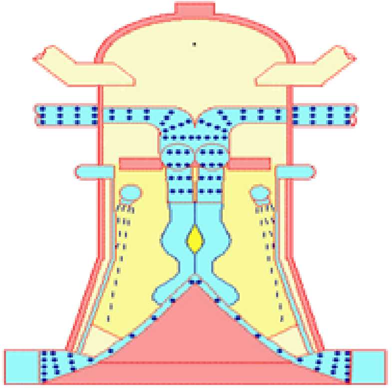


While closely related, US inertial fusion research falls into two distinct categories

	ICF	IFE
Objective	Study fusion ignition	Produce energy via fusion
Driver	Lasers, Z-pinch	Lasers, Heavy Ions, Light Ions, Z-pinch
Shot Rate	A few per day	5-10/second
Targets	Thousands of $ each	<$0.25 each
Funding Source	DOE-NNSA	DOE-OFES DOE-NNSA

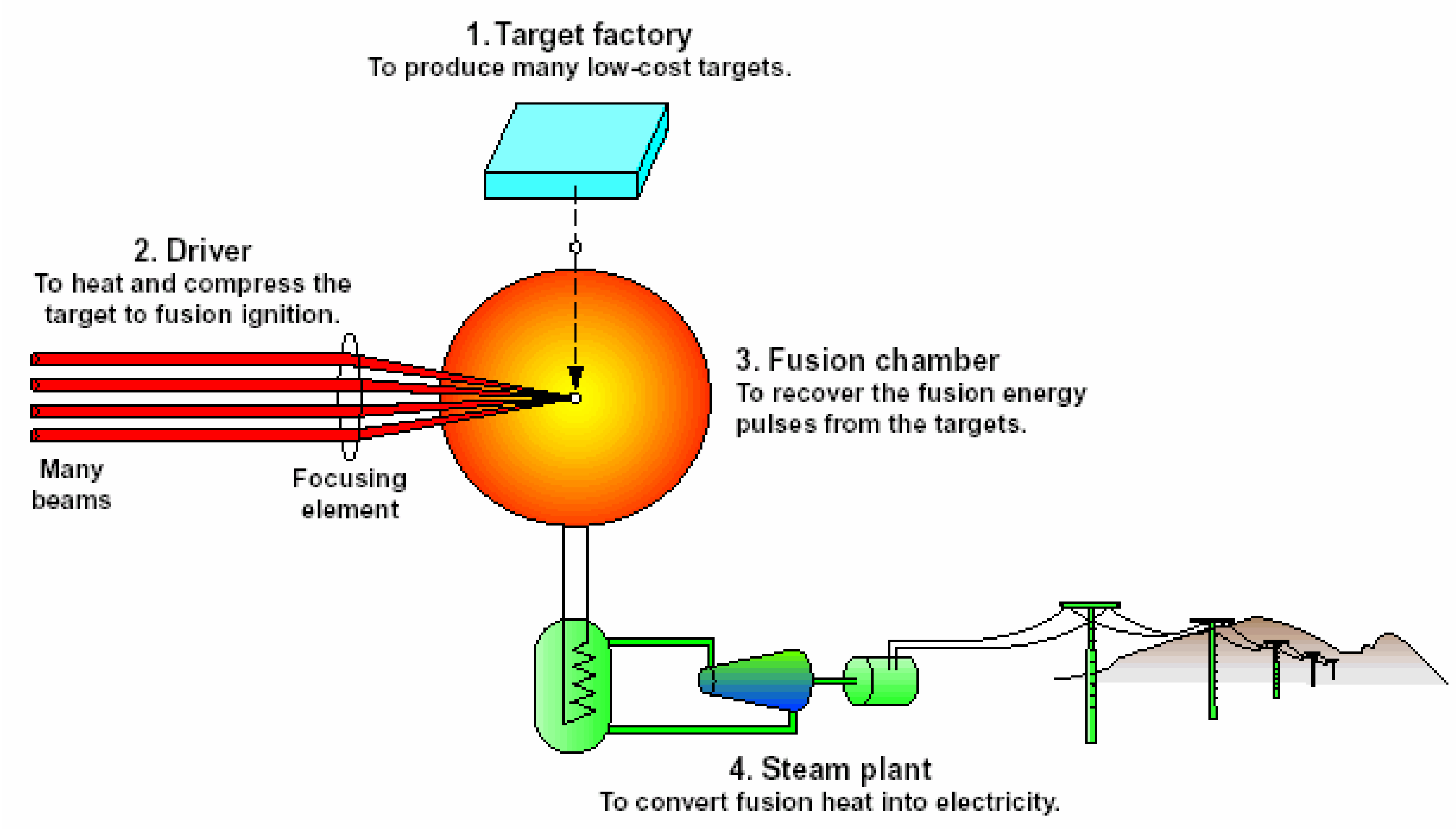


ICF *Shot Inside Omega*

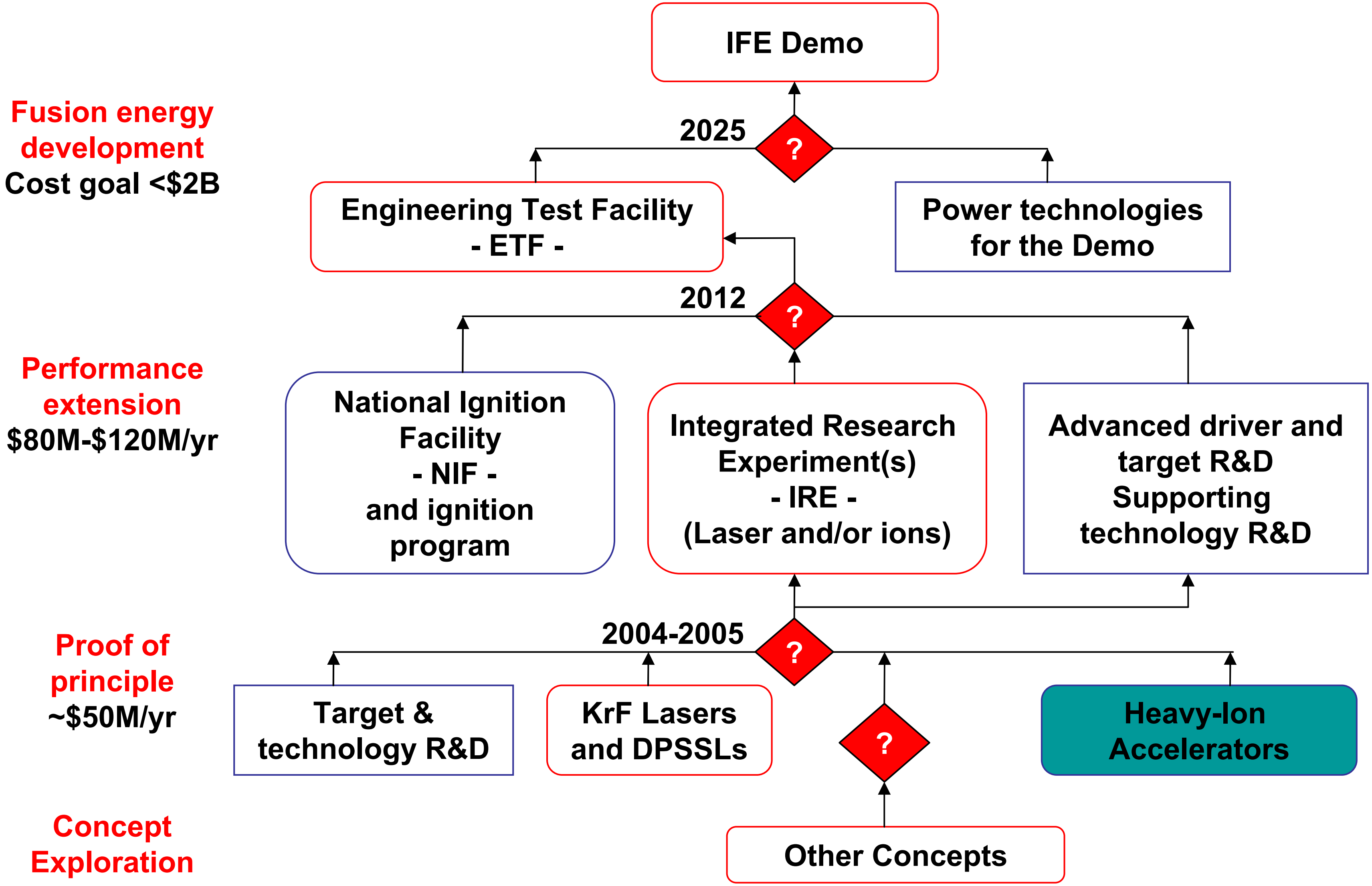


IFE *reactor concept*

An inertial fusion energy power plant will consist of four key parts



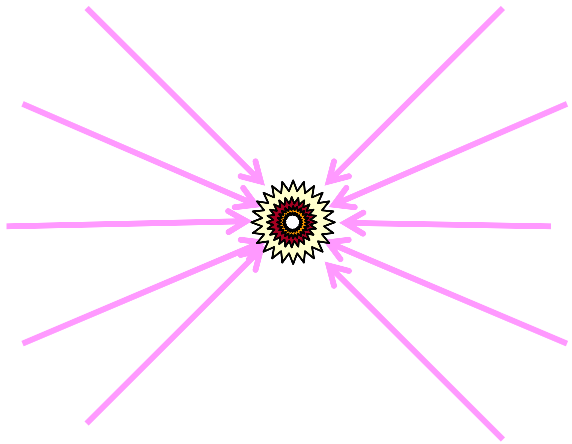
Inertial Fusion Energy Roadmap

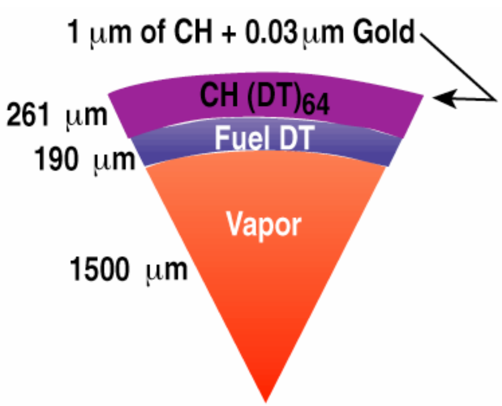


Target Overview

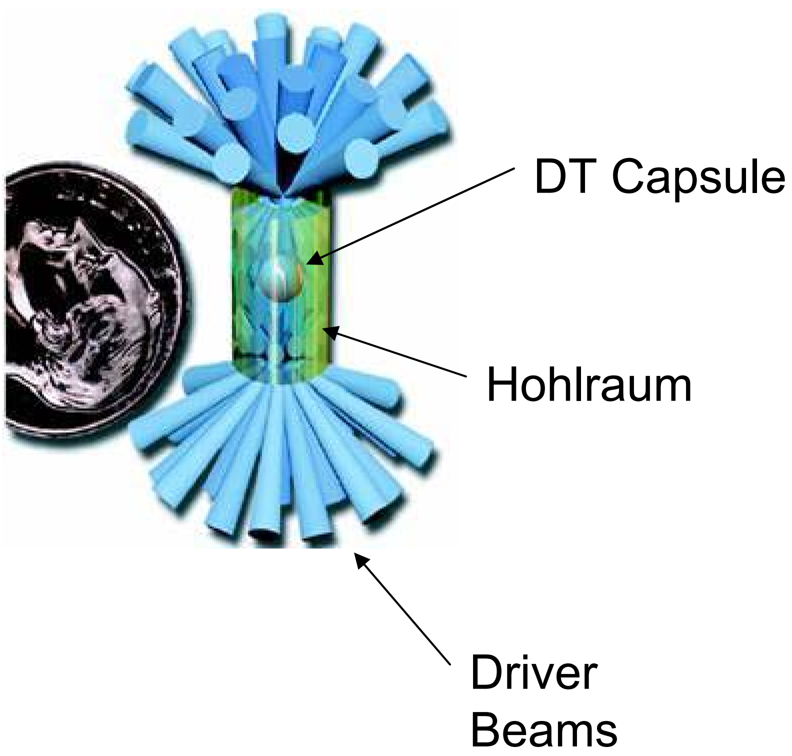
There are two types of targets—direct drive and indirect drive

Direct Drive Target

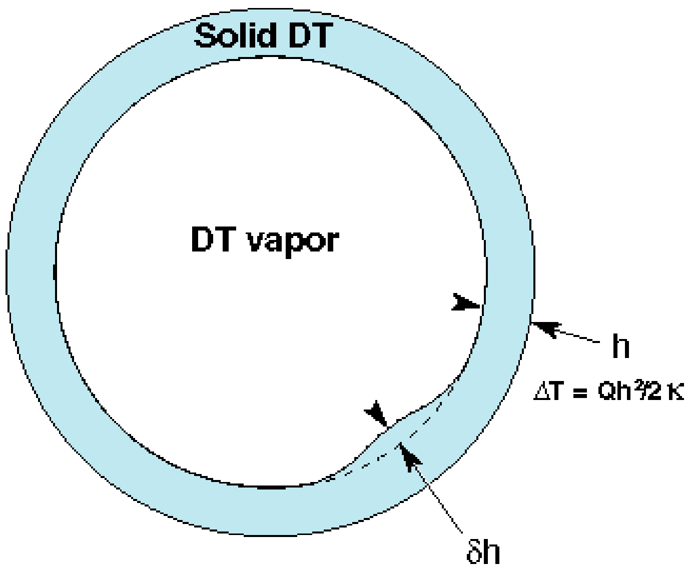




Indirect Drive Target



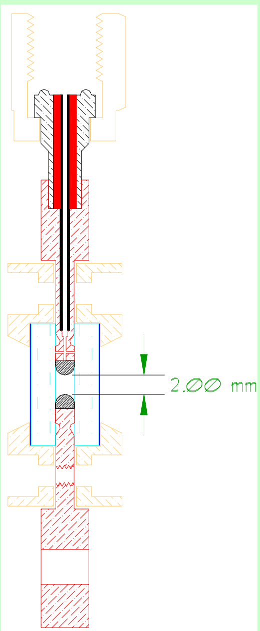
In the late 1980's it was discovered that solid DT naturally forms a smooth layer by "β layering"

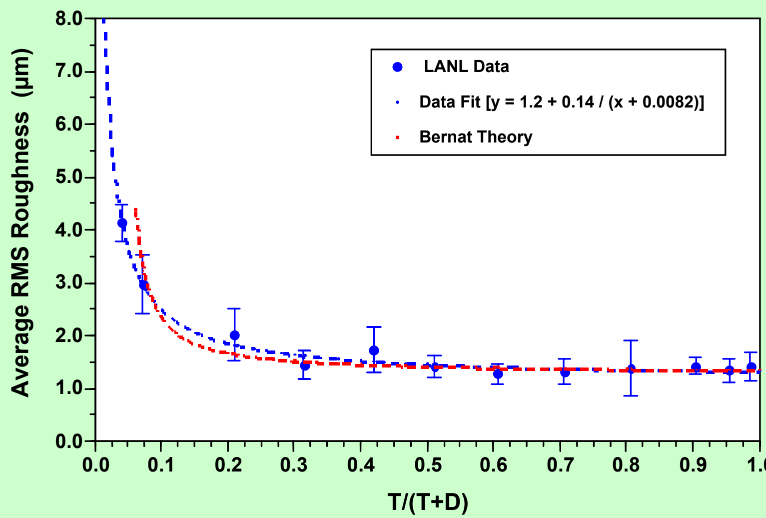


- **The bump height decreases because DT sublimes from the warmer spot and redeposits on colder surfaces**
- **Q can be increased by infrared heating**

DT ice layers have been formed both in cylindrical and spherical geometries that meet NIF specifications

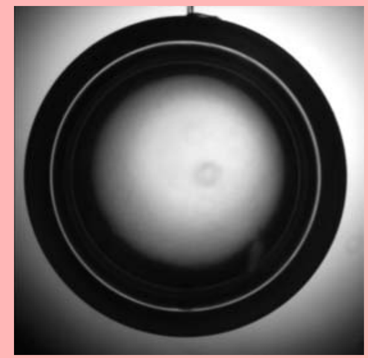
DT Ice Layer in Be toroidal cell (LANL)





- Surface roughness measurements were made as a function of D to T ratio.
- Ice layer roughness at 50/50 D/T is 1.45 µm rms including modes 2 and higher

DT Ice Layer in Spherical Geometry with Fill Tube (LLNL)

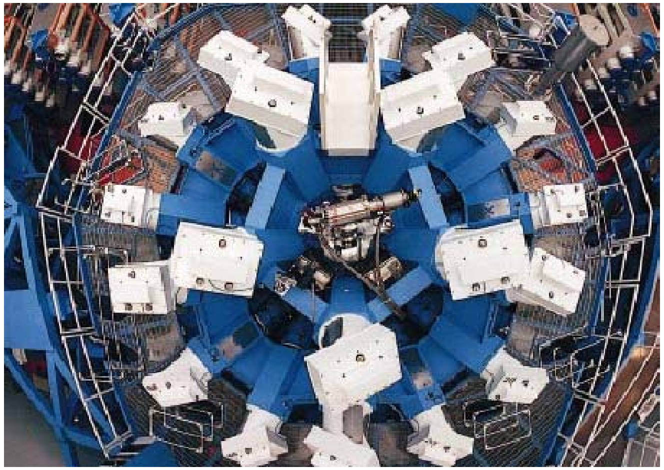


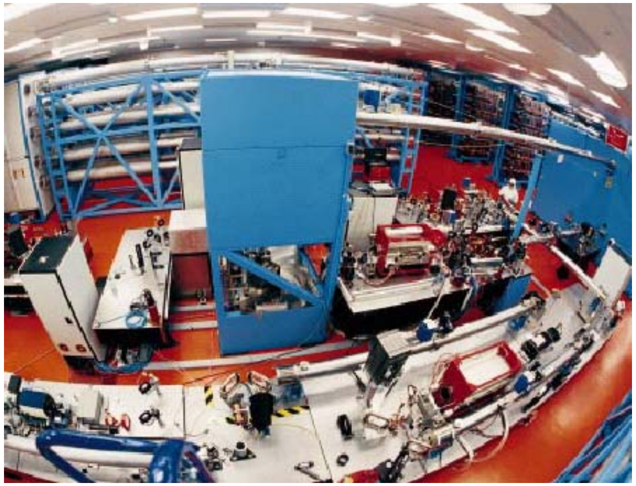
100 µm DT in ignition scale spherical shell with surface roughness rms ~0.3 µm

Omega

The OMEGA laser is presently the largest ICF laser operating in the US

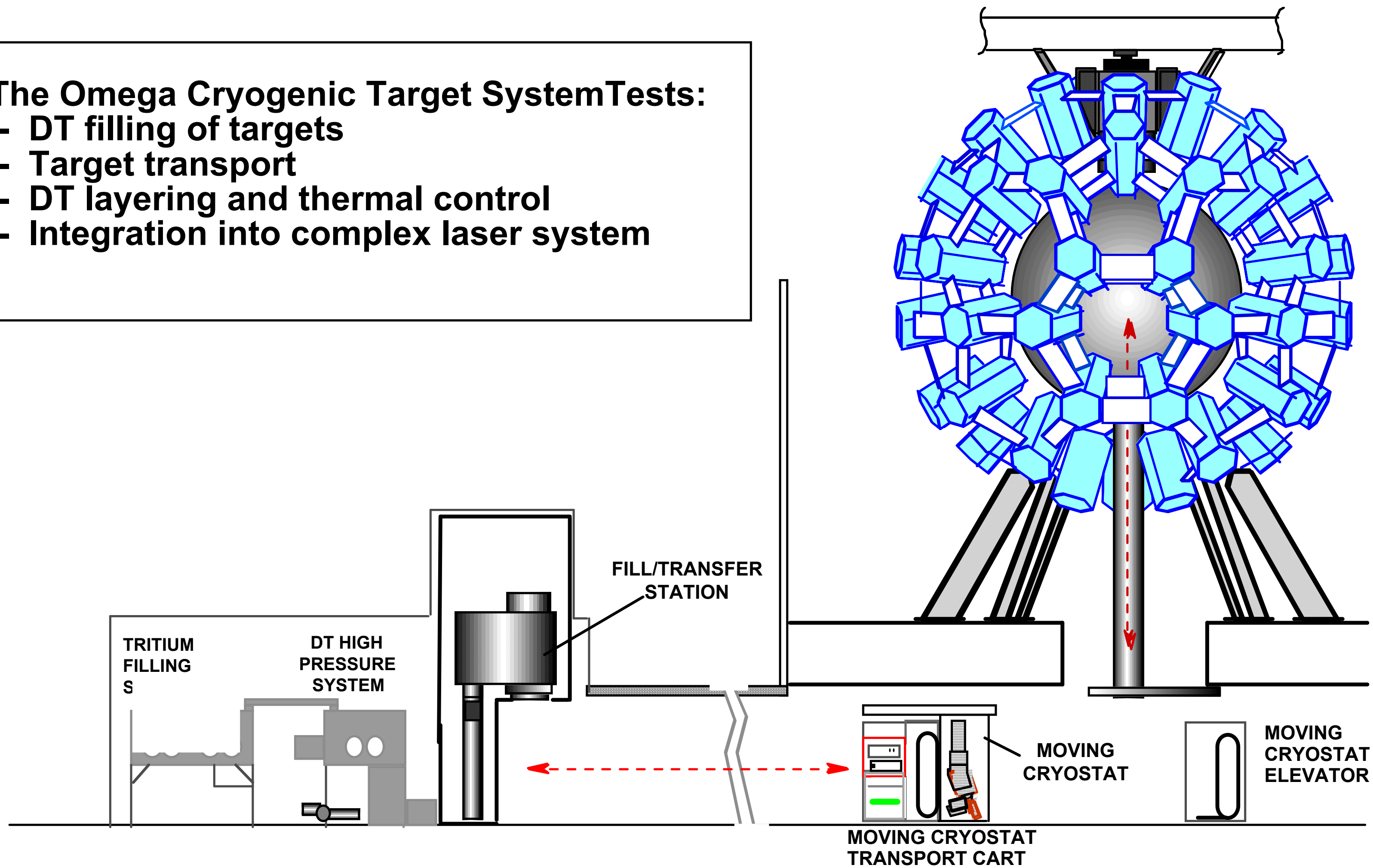
- The OMEGA laser at LLE is a 30kJ, 60-beam laser at 351-nm used to study high-energy-density physics present in laser-driven (direct-drive) Inertial Confinement Fusion (ICF) experiments
  - The current laser has been operational since 1995 and averages ~ 1200 experimental shots per year
  - The tritium facility delivered 385 tritium-filled targets over the past 5 years – each target is a 1-mm dia plastic and glass shells with an activity of up to 25mCi/target
  - Current cryogenic targets possess a considerably greater deuterium inventory. Will contain up to 750 mCi/target when tritium is used.
- Site tritium requirements
  - 1-gm tritium license
  - Maximum emission per stack is 2.2 Ci/year



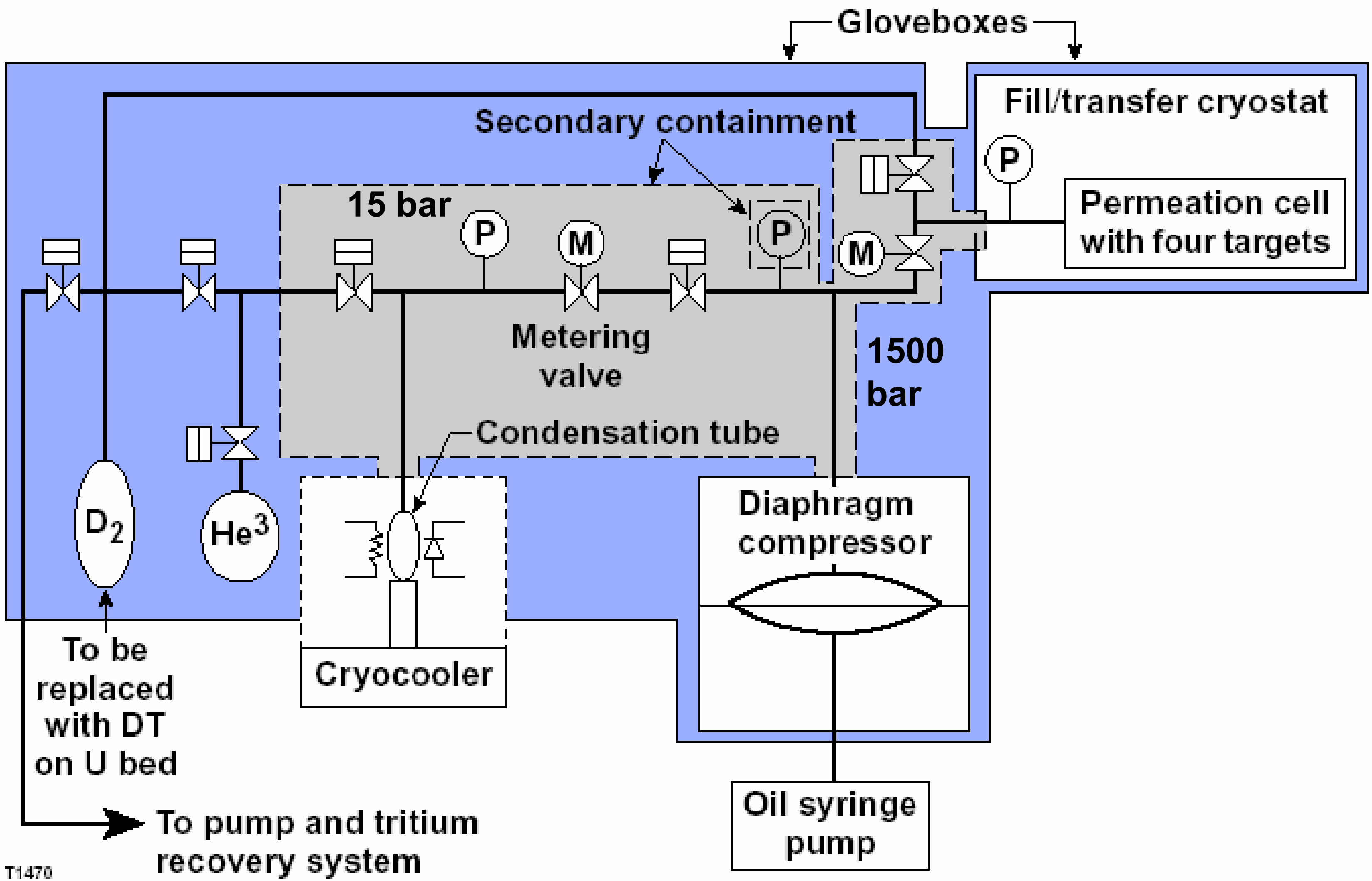


An integrated test of cryogenic ICF systems is underway on the OMEGA facility at U. of Rochester

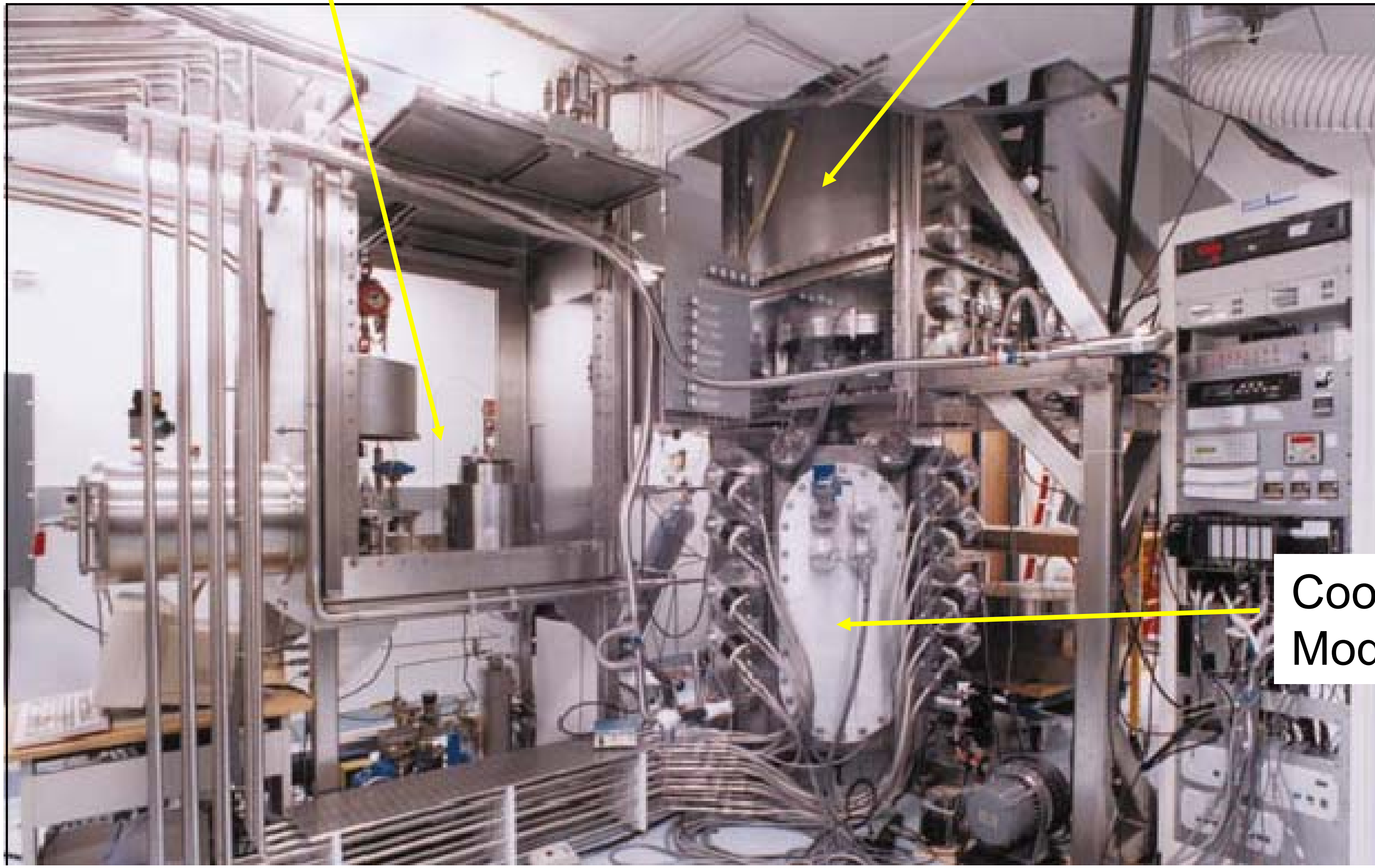
The Omega Cryogenic Target SystemTests:
- **DT filling of targets**
- **Target transport**
- **DT layering and thermal control**
- **Integration into complex laser system**



A cryocooler and a compressor are used to attain high pressure DT target filling (1500 bar maximum)



High-pressure fill system and associated cryogenic components

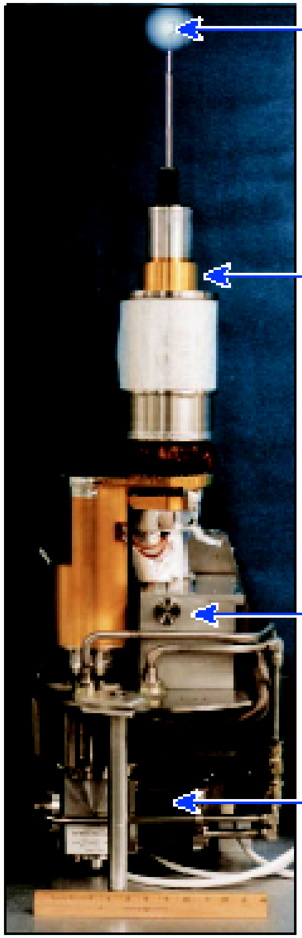


The Omega moving cryostat is an example of unique ICF systems that work with tritium components

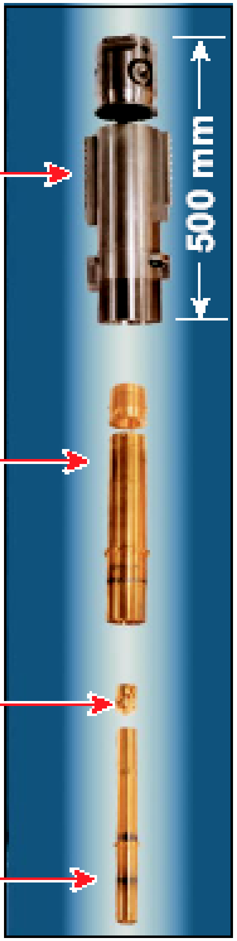
Design and performance:

- **Upper shrouds detach from the base to expose the target.**
- **The cryostat base contains a four-axis target positioner and a cryocooler.**
- **The target can be maintained at 17 K; temperature stability is better than 10 mK.**

Cryostat base



Upper shrouds (exploded view)

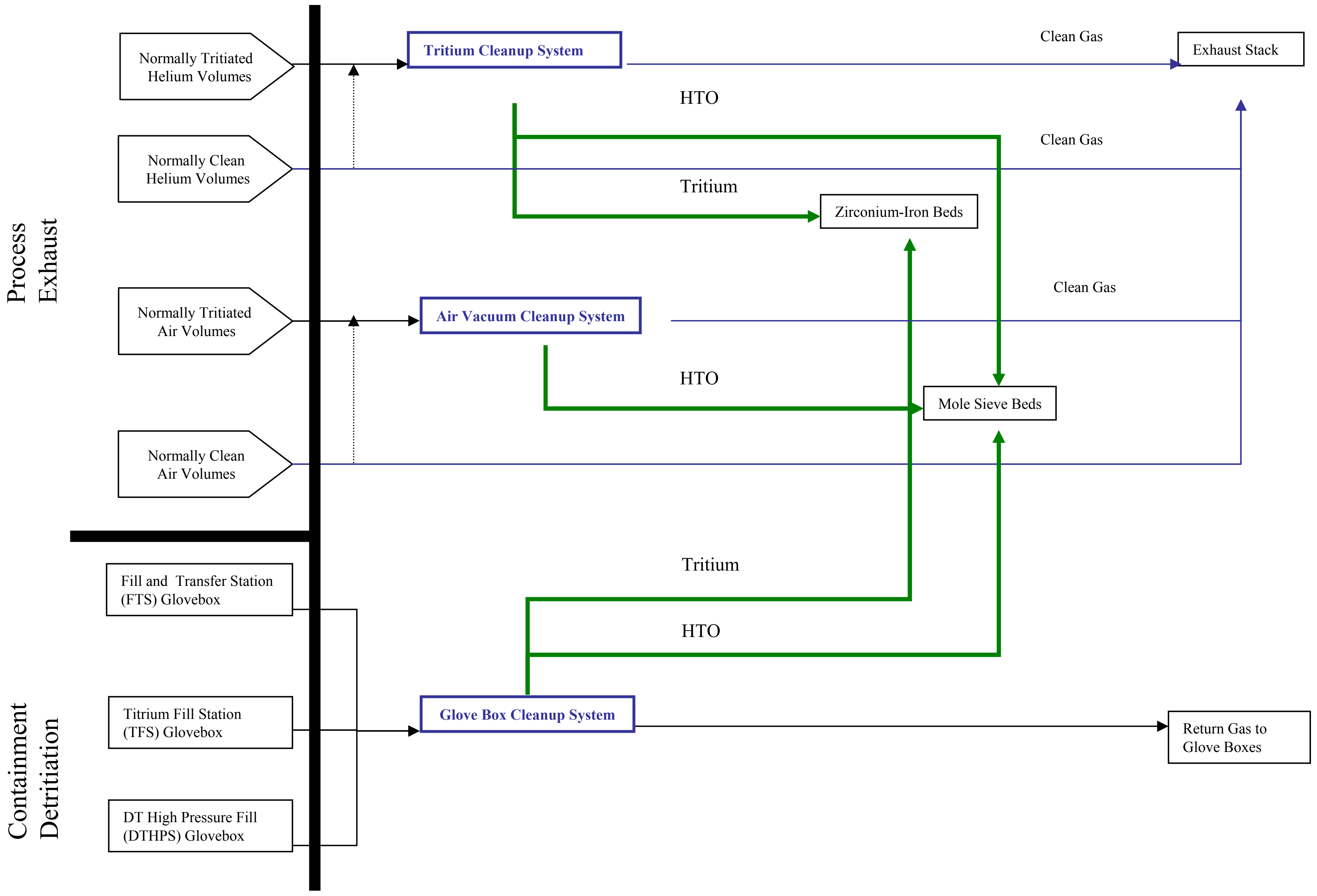


T1462a

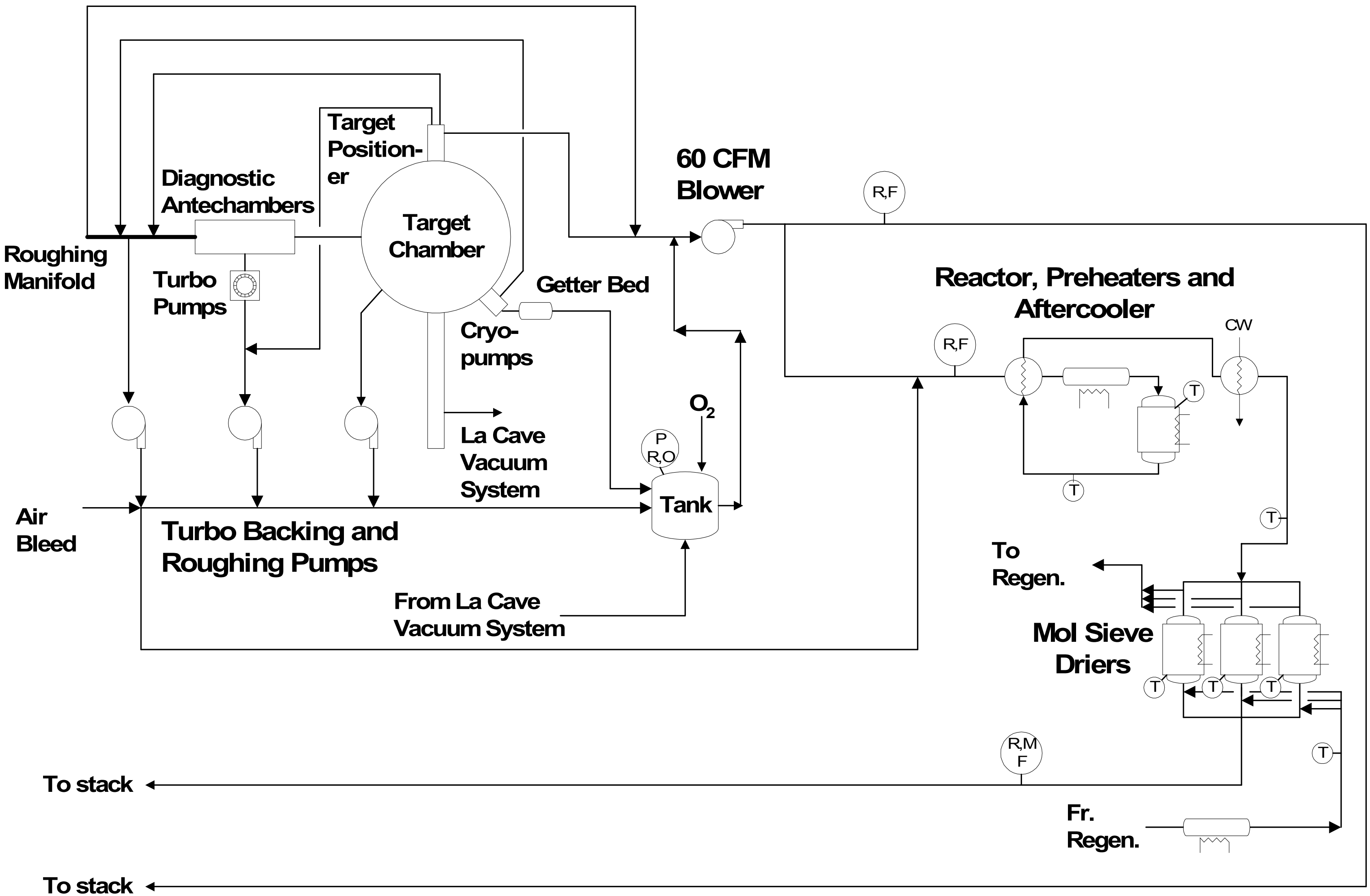
There are two major tritium cleanup systems at Omega

- **“RM157-TRS” consists of three subsystems**
  - “Air-vacuum Cleanup System”
    - Processes tritiated air from antechambers and decontamination activities
    - Uses catalytic cracking and molecular sieve driers
  - “Tritium Cleanup System”
    - Processes tritiated helium in primary process equipment
    - Uses metal hydride gettering
  - “Glovebox Cleanup System”
    - Processes secondary containment of three tritium-containing gloveboxes
    - Uses metal hydride gettering and molecular sieve cryotrapping at 77K
- “TC-TRS”
  - Process target chamber, diagnostics and associated atmospheres
  - Catalytic oxidation, adsorption

Overview of Omega "RM157-Tritium Recovery System"

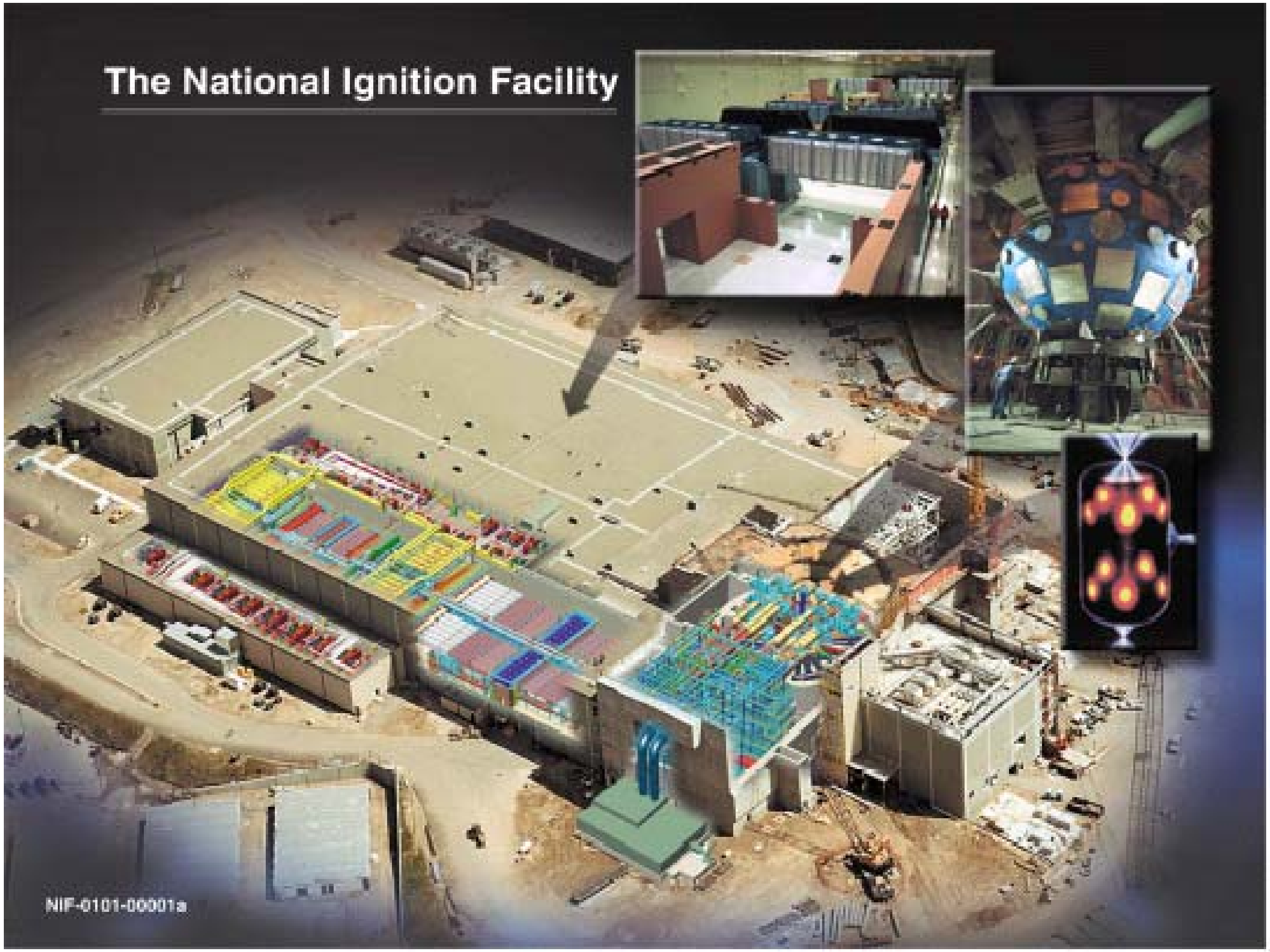


Target Chamber atmosphere will be processed with the "TC-Tritium Recovery System"



The National Ignition Facility will be the flagship US ICF facility

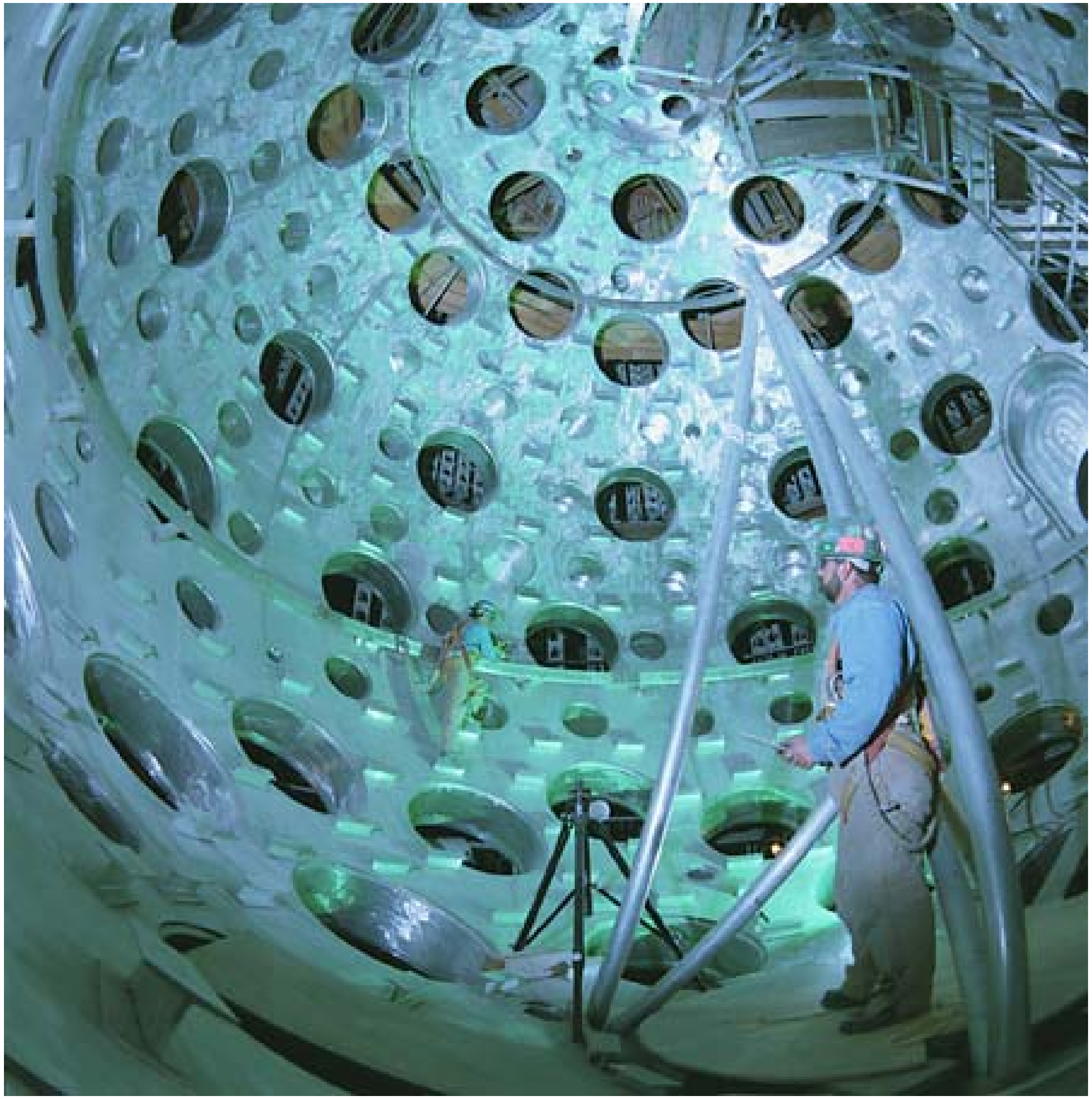
- Nd glass laser
- 192 beams
- 1.8 MJ
- >700 shots/year
- 10 m dia. target chamber
- First light: 2nd quarter '03
- Construction complete: 9/08
- Ignition: 2011
- FY'02 construction funding: $245M
- Total Cost: $3.4B



The NIF target chamber has a 10 m diameter

(11/00)

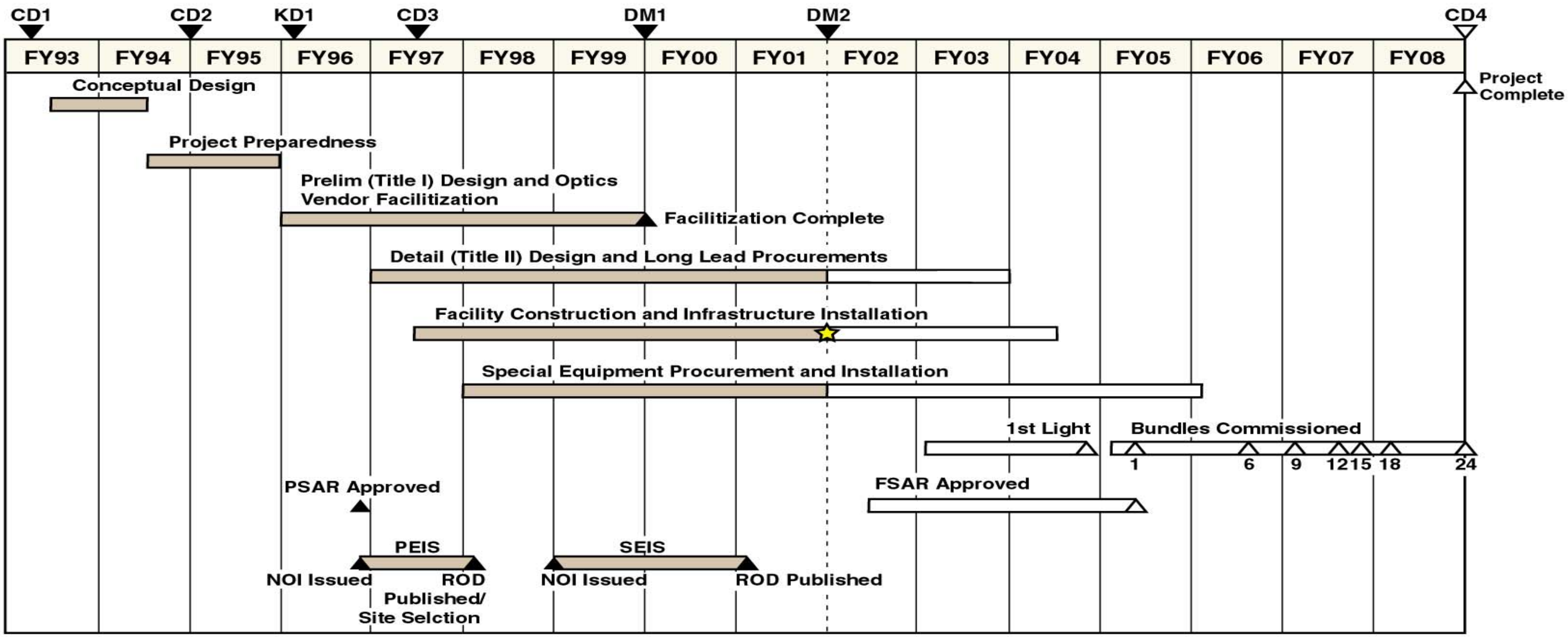
View inside the target chamber while performing position measurements



(6/00)

NIF conventional facility construction was completed in September 2001

NIF Baseline Schedule

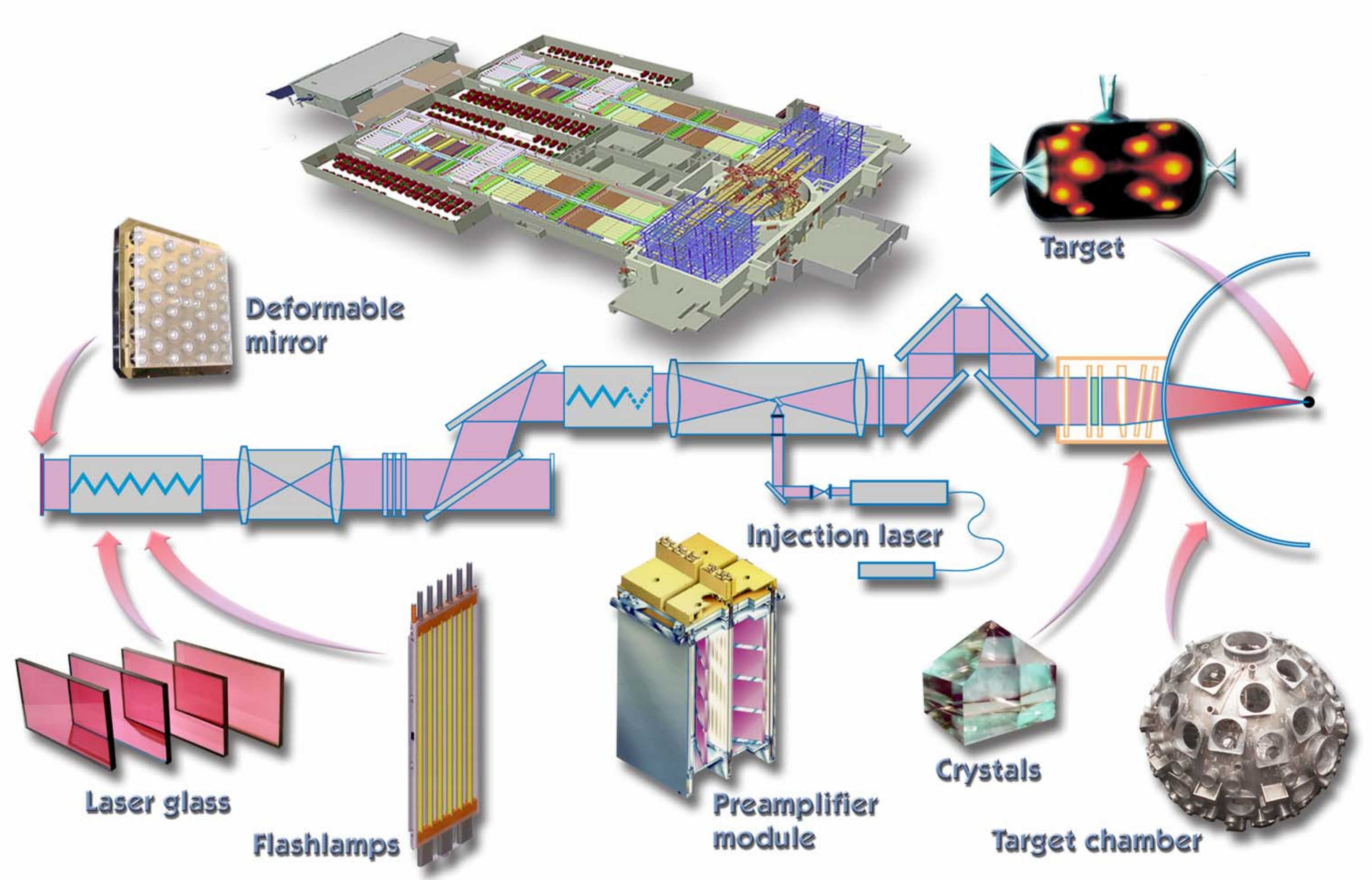


CD1 - Approve Mission Need
CD2 - Approve New Start
KD1 - Delliums' Process-NIF Study Complete
CD3 - Approve Construction Start

DM1 - Optics Facilitization Complete
DM2 - End Conventional Construction
CD4 - Approve Operation Start

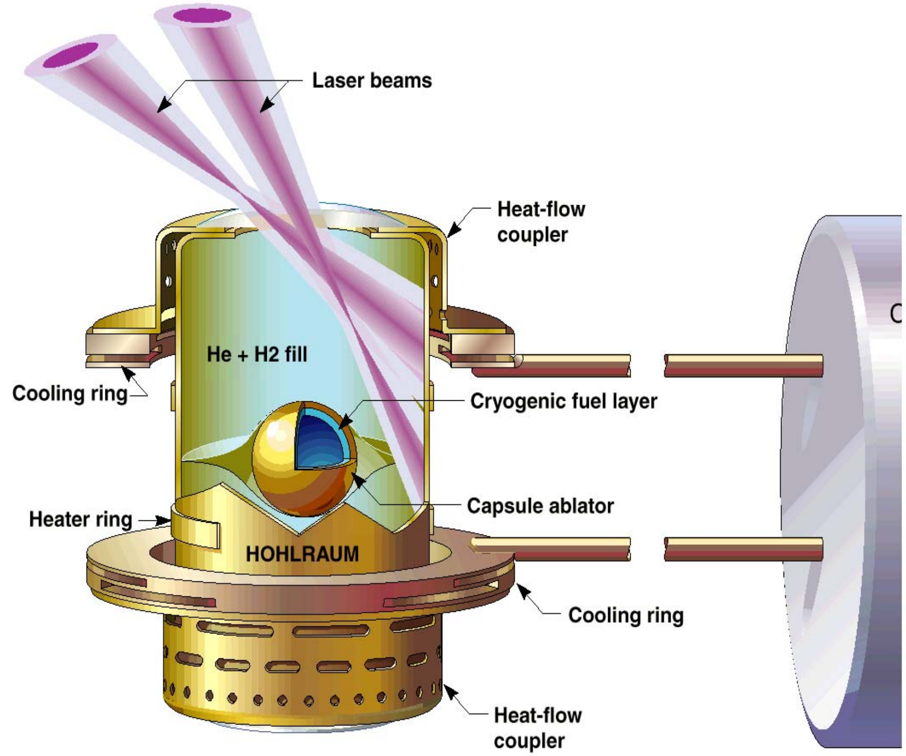
NIF-0801-02499-r1
02SM/pdd

A variety of technologies are needed for NIF

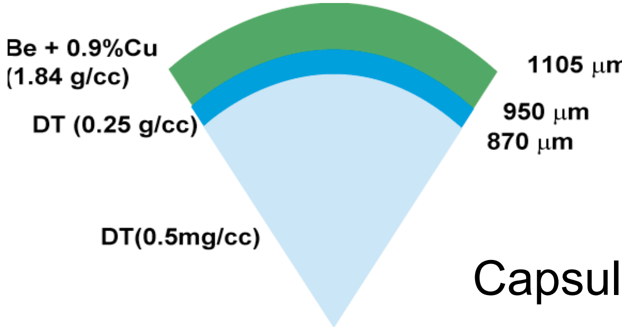


NIF indirect drive target

Beams enter either end of cylindrical hohlraum

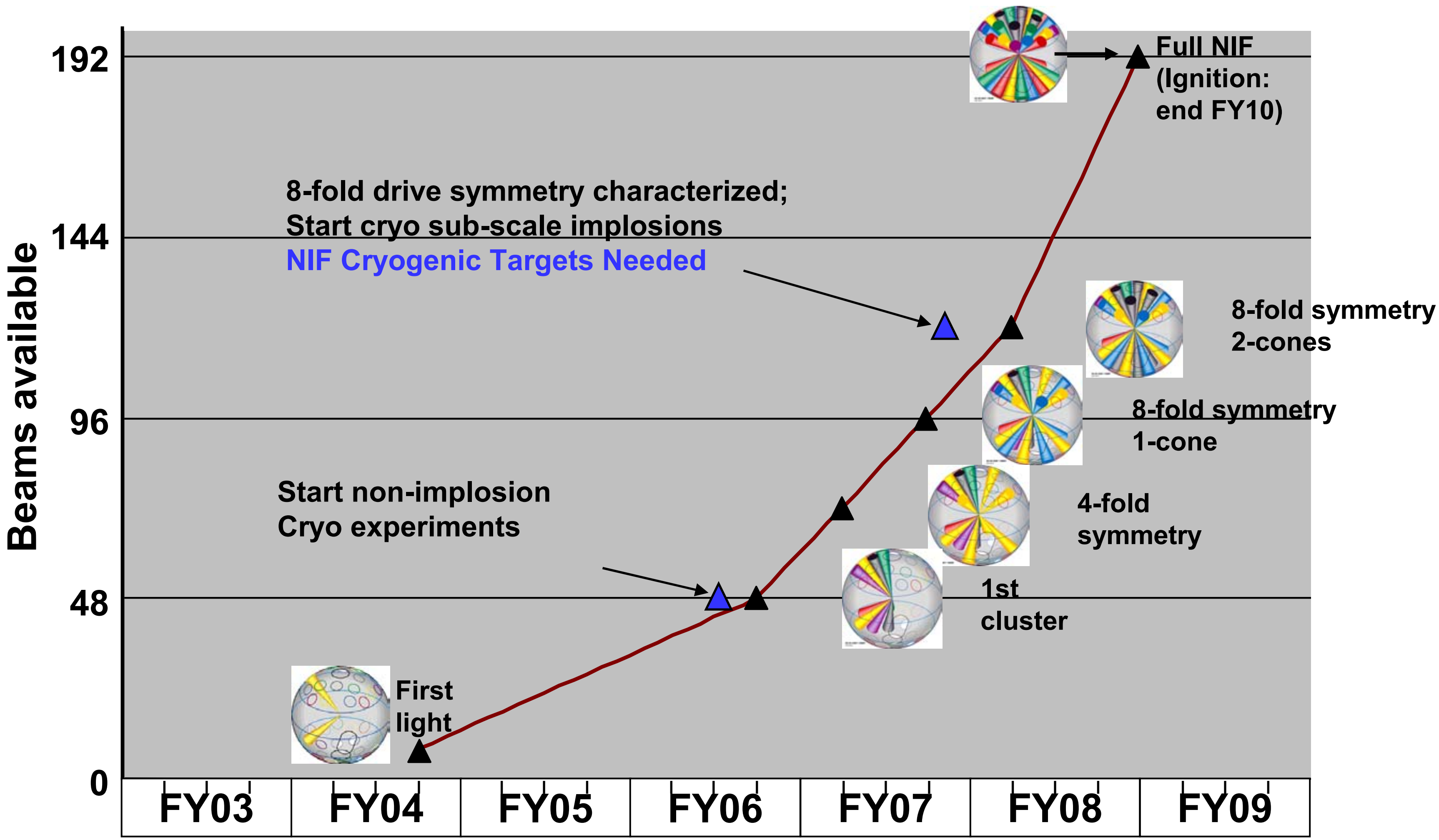


Hohlraum detail



Capsule detail

Schedule for ignition on NIF



NIF target development organization

Indirect Drive Ignition Plan (Target portion only)

Target Design Activities (LLNL, LANL)

- Capsule specifications
- Hohlraum specifications

Capsule Development Activities

- Beryllium-copper (LANL)
- Polymer (LLNL)

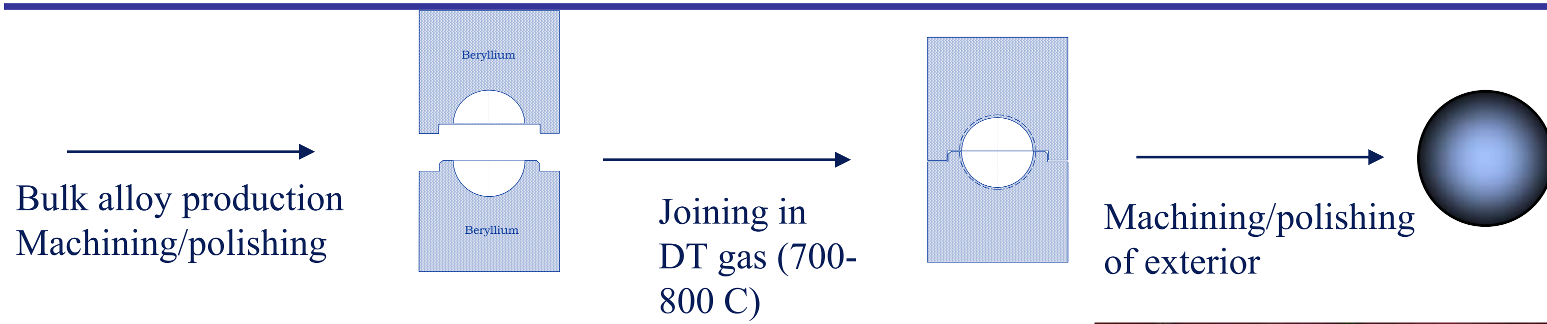
DT Layering and Cryogenic Hohlraum Development (LLNL, LANL)

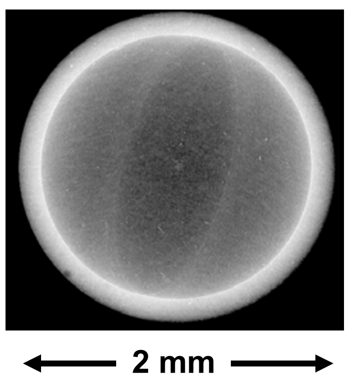
- DT ice layer symmetry and surface finish
- Thermal symmetry of capsules in cryogenic hohlraums
- Characterization of cryogenic DT ice layers in Be and polymer capsules

DT Fill and Target Fielding Systems (LLNL, LANL, GA, UR)

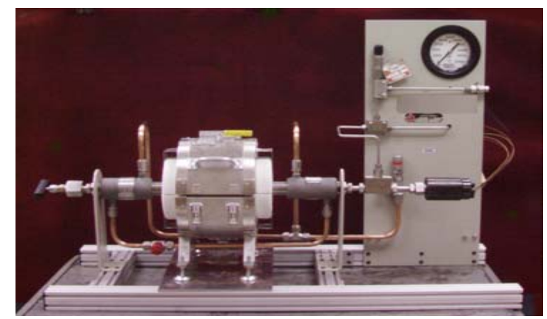
- Beryllium DT fill system (LANL)
- Polymer fill system (LLNL)
- Target fielding systems (LLNL)

The approach to producing beryllium-copper capsules is to bond and machine hemishells in DT gas

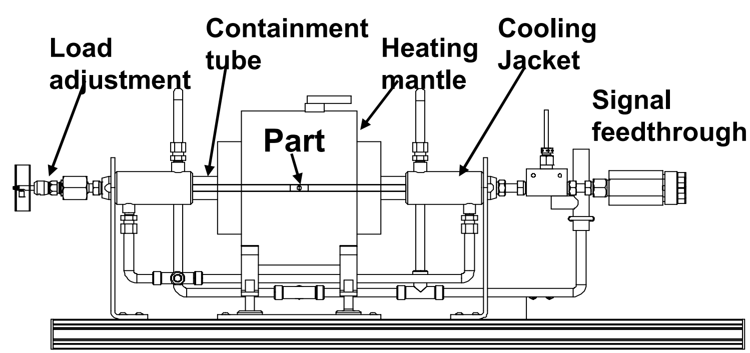




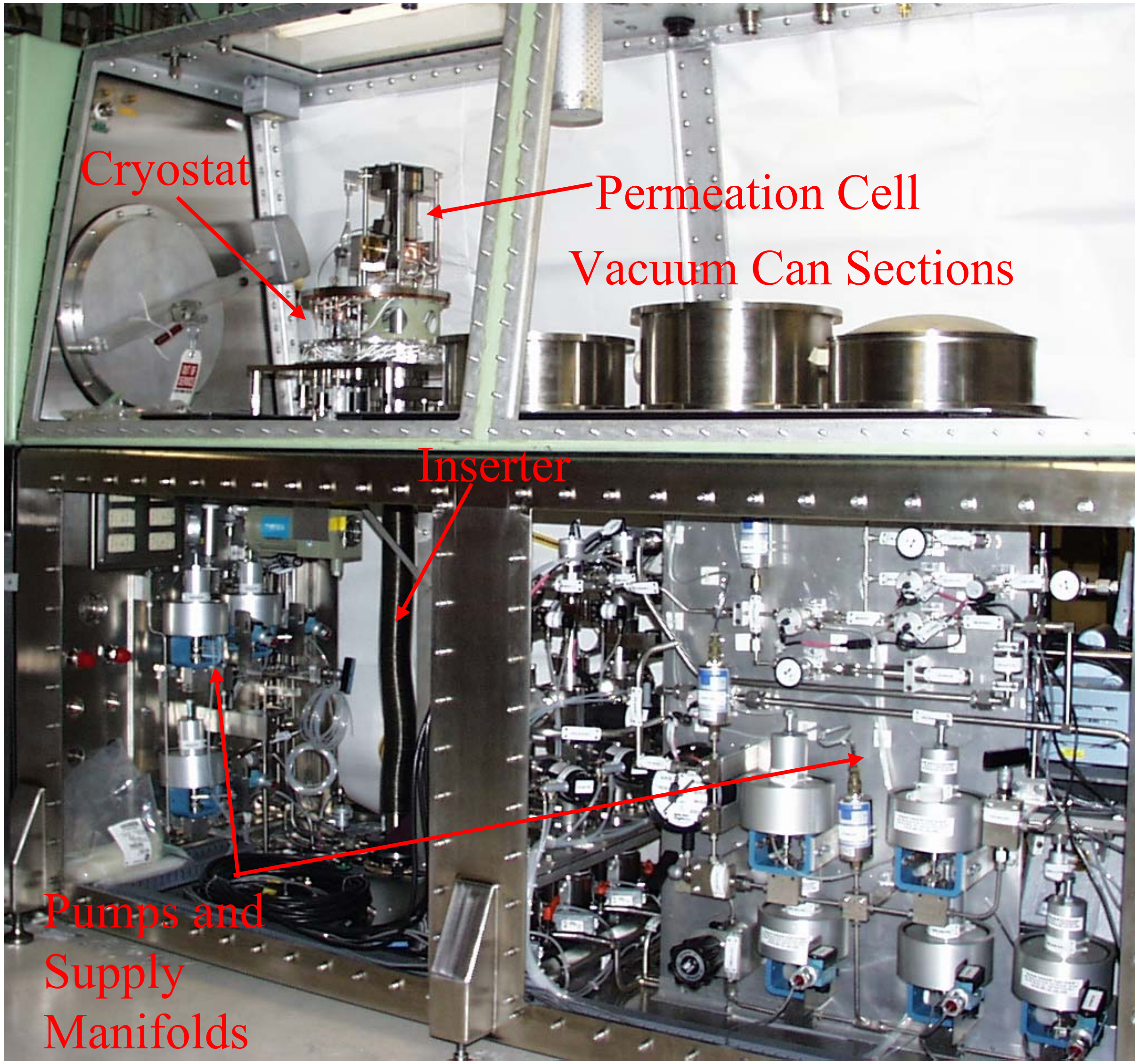
- Bonding and machining of NIF-sized hemishells has been demonstrated
- Filling of bonded hemishells with 50 atm deuterium has been demonstrated



Be Experimental Deuterium Fill System

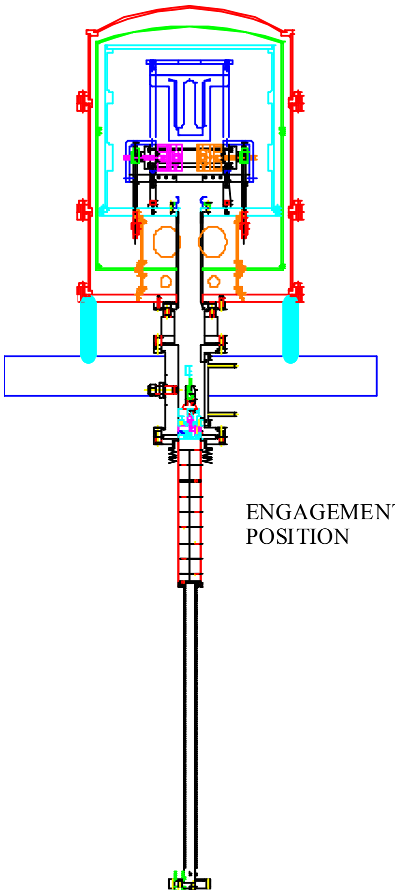


First studies of DT ice layers in capsules without fill tubes will be conducted in the near future in the LANL Cryogenic Pressure Loader



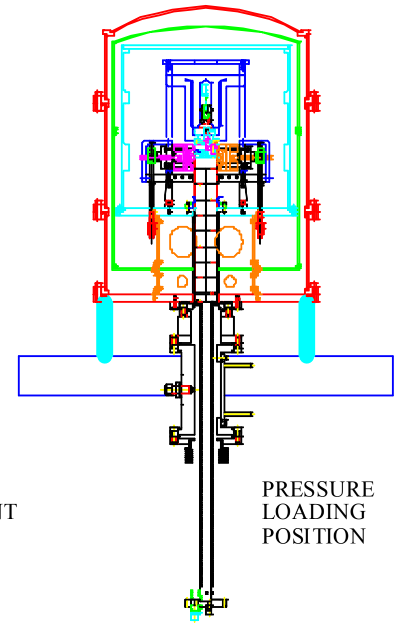
- Diffusion fill polymer targets to 1100 atm DT and cool to cryogenic temperatures
- Study DT ice layers in hohlraums
- Evaluate DT effects on hohlraum polymers
- Evaluate DT migration and obtain DT operating experience

Details of the Cryogenic Pressure Loader



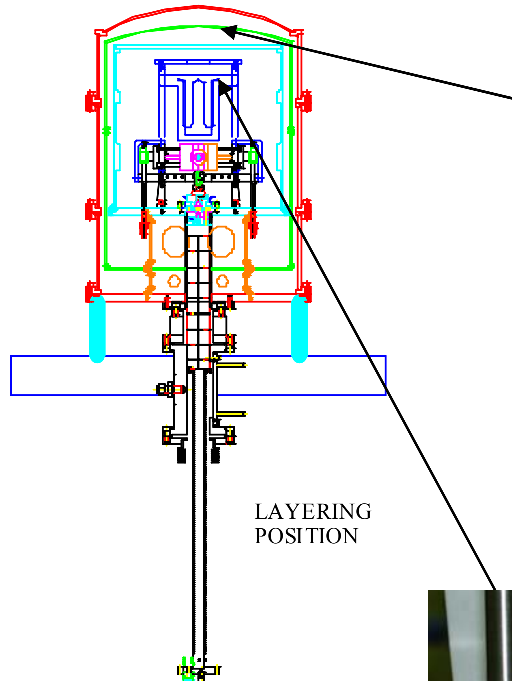
ENGAGEMENT POSITION

1. Mount target on inserter
2. Raise inserter



PRESSURE LOADING POSITION

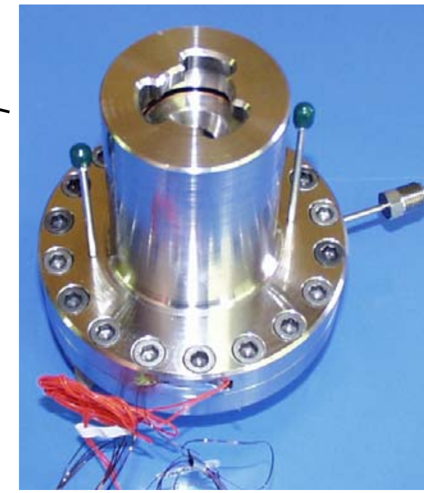
3. Engage breechlock
4. Pressurize diaphragm
5. Pressurize DT space
6. Permeation fill target
7. Cool cryostat to 20 K
8. Pump away excess DT
9. Release diaphragm pressure
10. Disengage breechlock



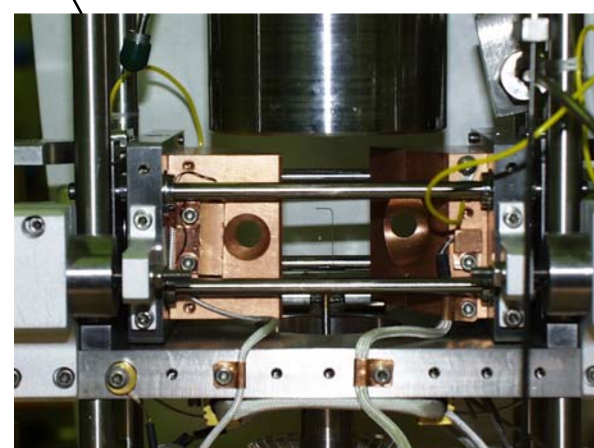
LAYERING POSITION

11. Lower inserter
12 Bring layering hemispheres together to form sphere
13. Observe beta layering

Permeation Cell

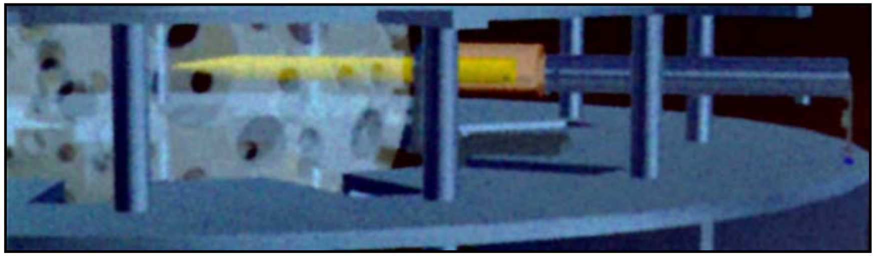


Layering Sphere

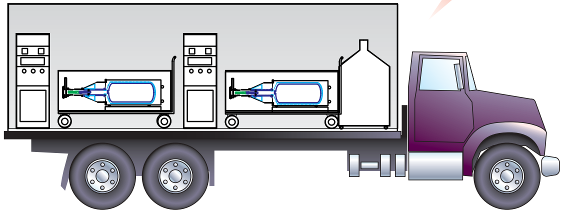


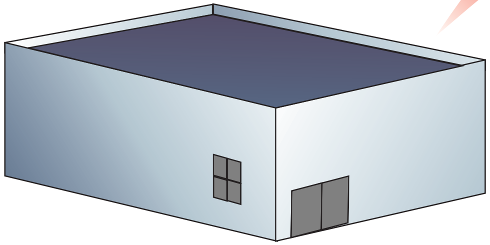
The cryogenic target systems project will provide the equipment to field ignition targets

Target and support cryostat are positioned in NIF chamber



Filled targets are transported cryogenically





Tritium fill facility: fully assembled targets are cooled under high pressure after filling

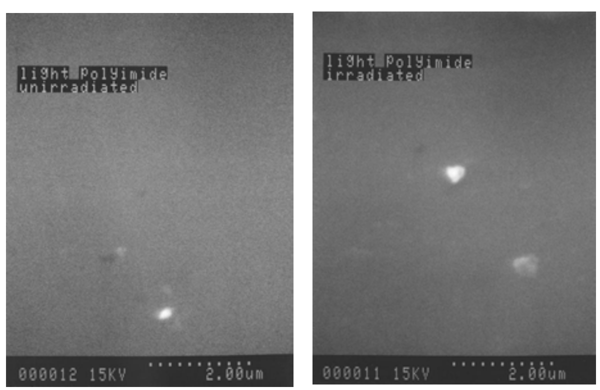
High pressure DT exposure tests on polyimide films were recently conducted

High pressure sample containment vessel

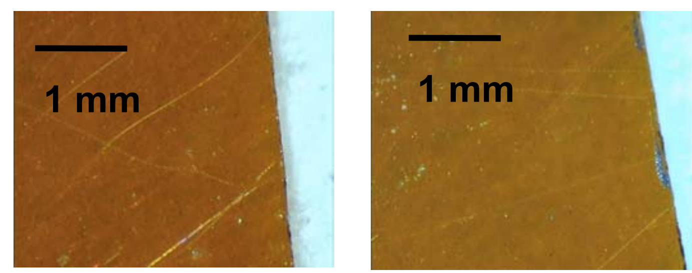
- Polyimide is one of the baseline ignition targets for NIF
- It must be determined whether DT exposure influences polyimide surface morphology
- Kapton and Upilex polyimide film samples were exposed to high pressure DT
  - 350 atm, 5 days
- Simulates NIF fill and shipment

SEM and optical images of DT-exposed and unexposed samples revealed no significant changes in surface morphology

Exposed and unexposed SEM images

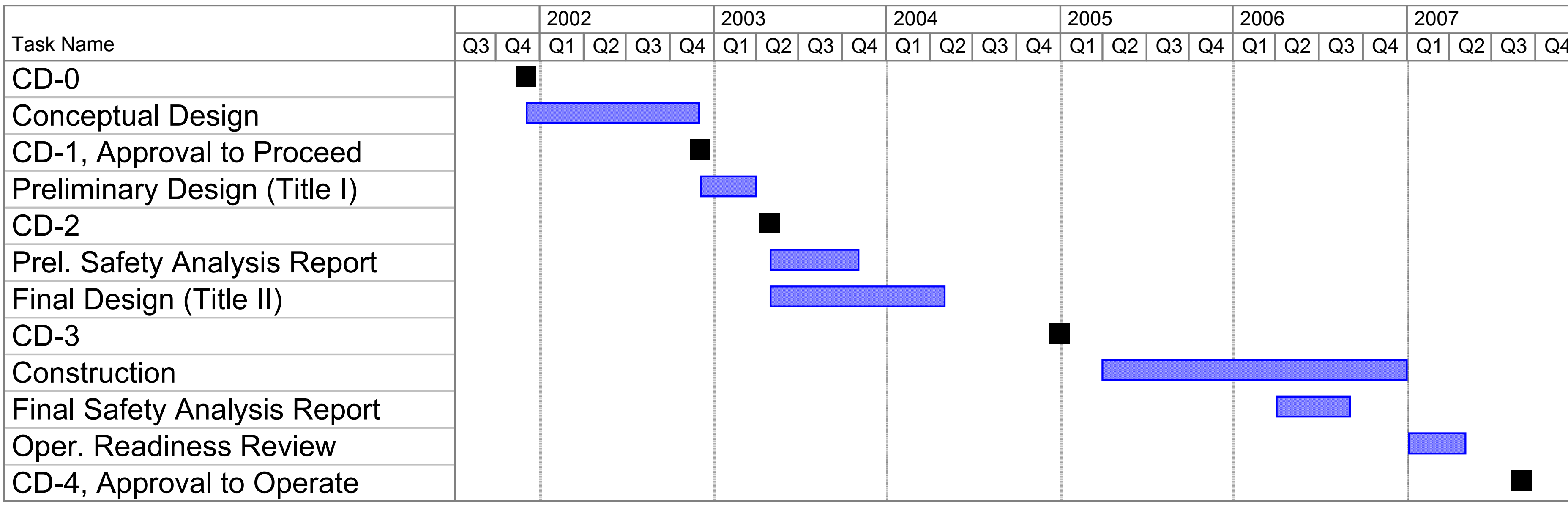


Exposed and unexposed optical images

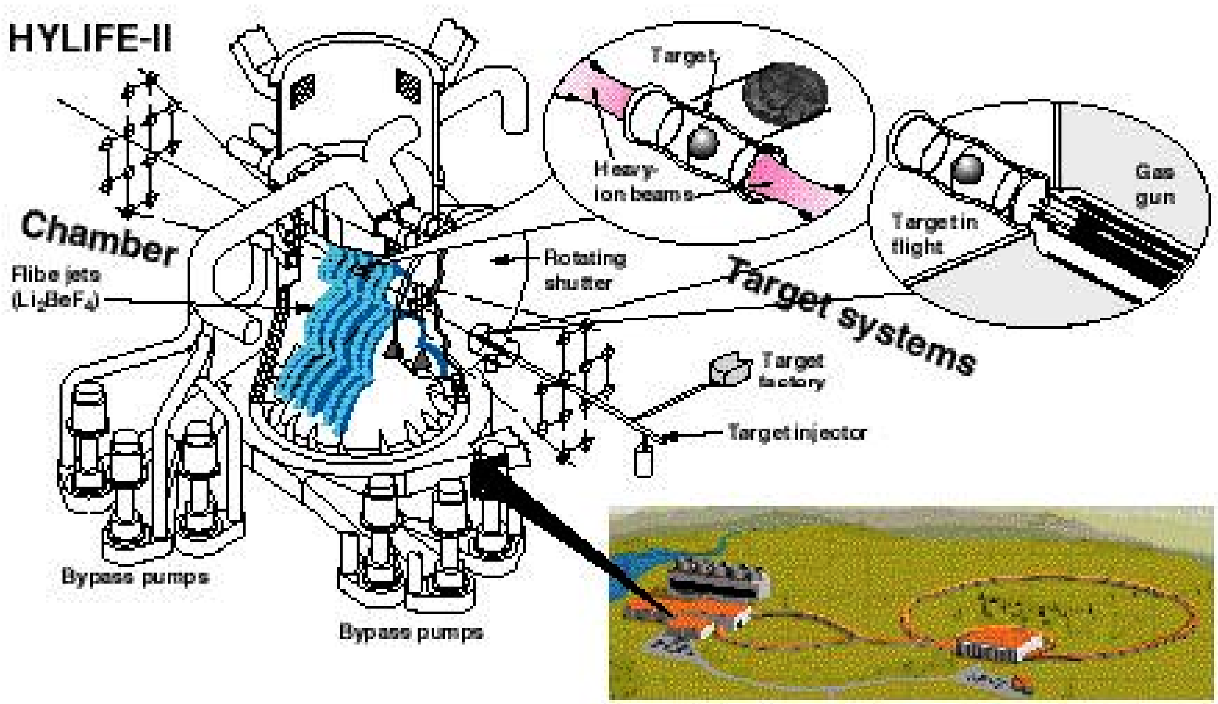


Tritium facilities at LLNL will support NIF DT needs

Preliminary Schedule for LLNL Hydrogen Isotope Research Center



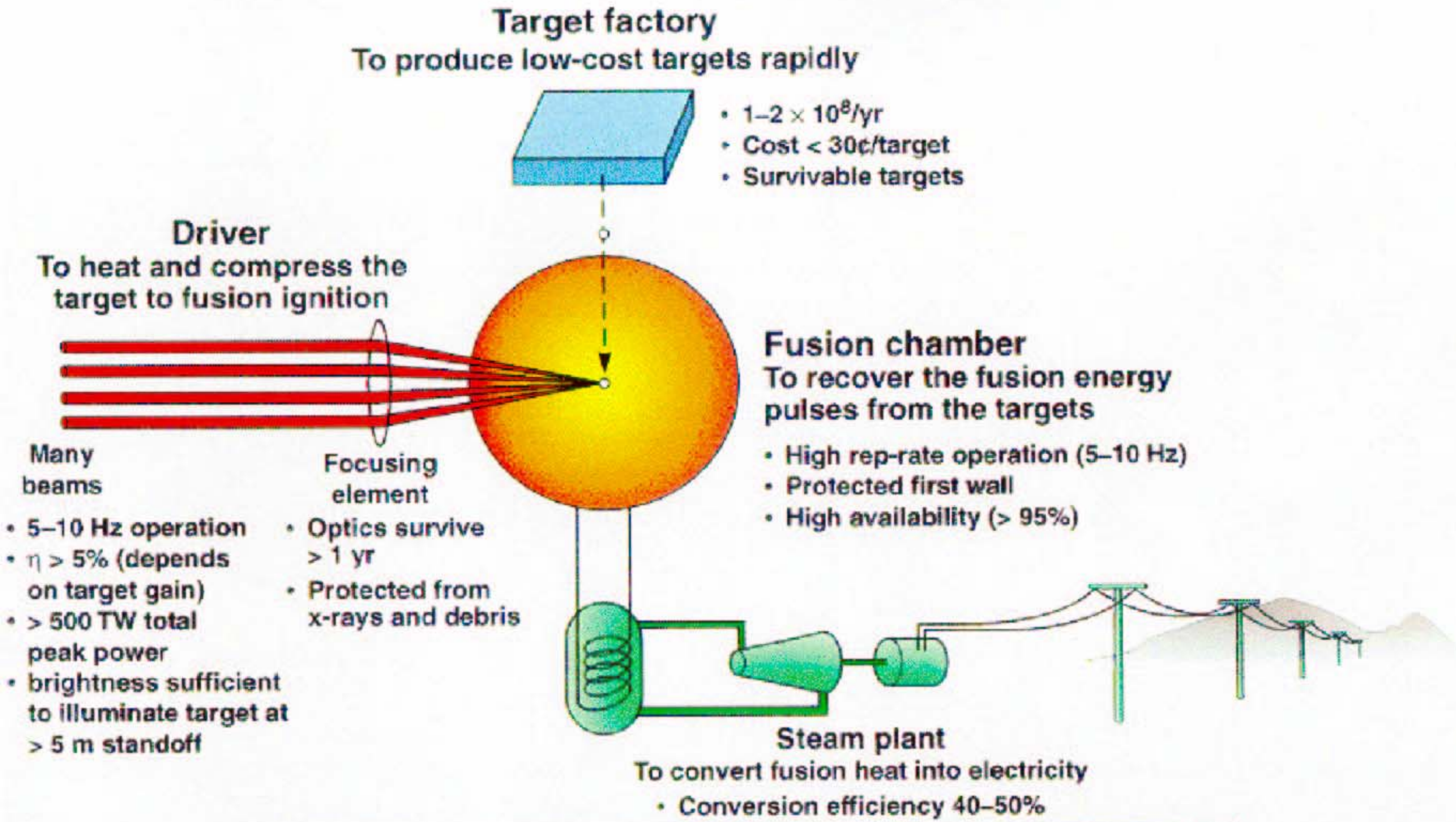
IFE


HYLIFE-II
Chamber
Flibe jets
(Li2BeF4)
Bypass pumps
Bypass pumps
Target
Heavy-
ion beams
Rotating
shutter
Gas
gun
Target in
flight
Target systems
Target
factory
Target injector

In recent years there has been increasing US attention to IFE

- “A strong IFE program is a proper and important component of the restructured OFES/DOE program.”—*FESAC report on IFE, 1996*
- “The Panel has identified the achievement of a more integrated national program in MFE and IFE as a major programmatic and policy goal in the years ahead.”—*FESAC report on Priorities and Balance, 1999*
- A more integrated approach to managing ICF/IFE has been established in response to statements such as “. . .some strengthened means for overall coordination should be established.”—*SEAB report on Fusion Energy 1999*
- A portion of NNSA funding for ICF has been earmarked for high rep rate laser IFE for the past few years.

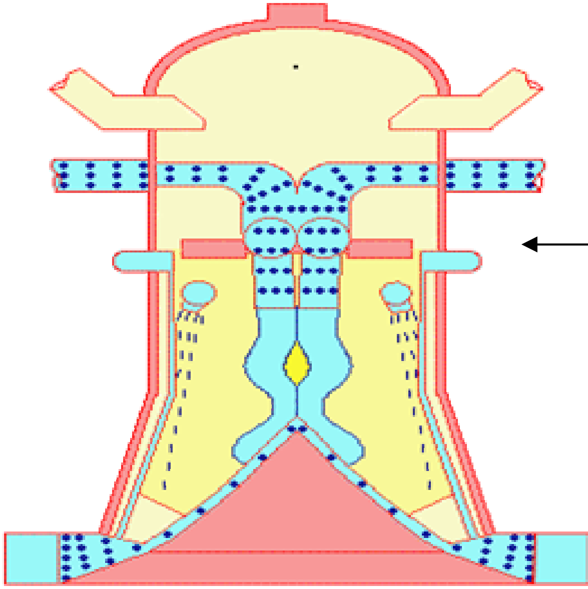
Inertial fusion energy (IFE) power plants of the future will consist of four parts



An IFE power-plant would ignite five to ten targets per second to produce as much electricity as today's one gigawatt power plant

The IFE program is oriented around two major concepts

HYLIFE-II Chamber

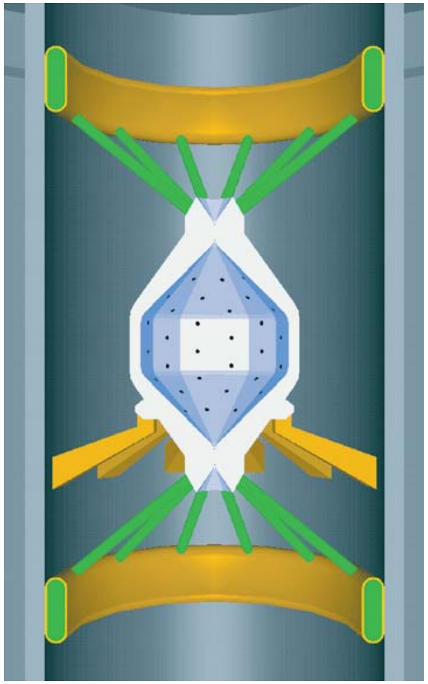


Different scales
First wall radius:

HYLIFE-II = 3.5 m

SOMBRERO = 6.5 m

SOMBRERO Chamber



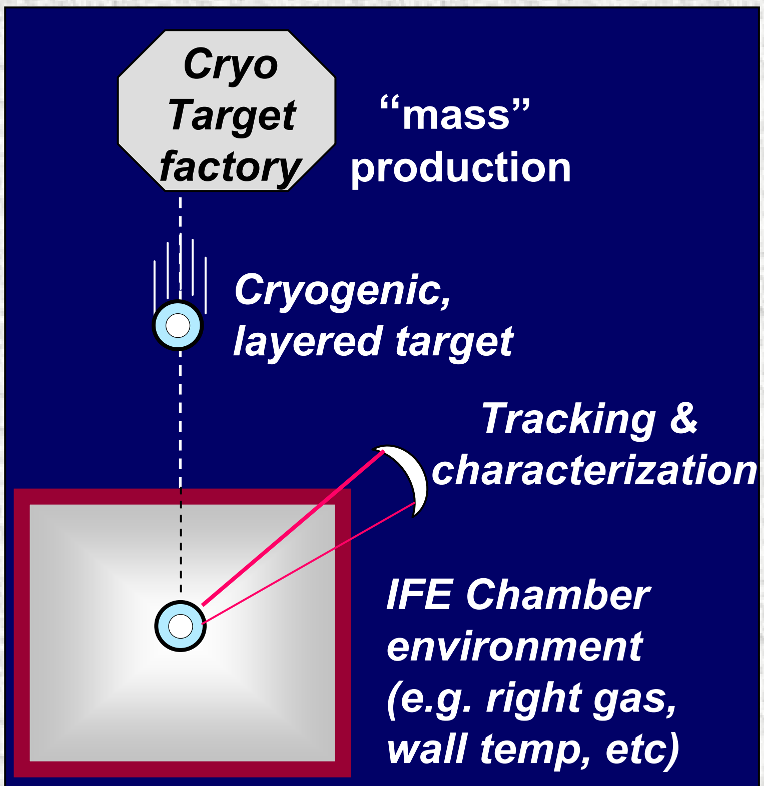
Heavy ion driver
Indirect drive target
Thick-liquid-wall chamber

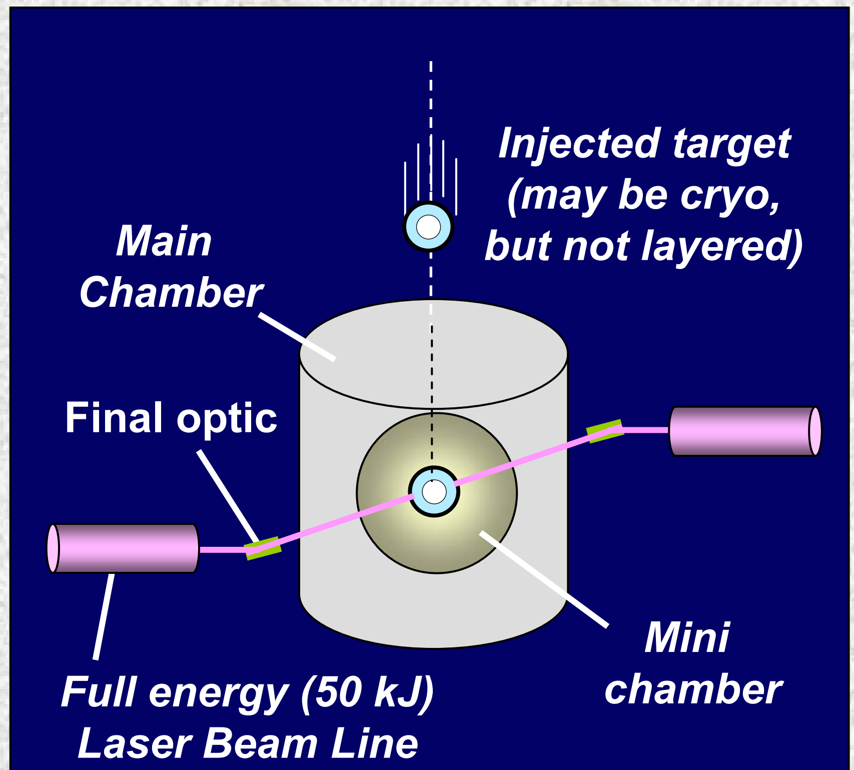
Laser driver
Direct drive target
Dry-wall chamber

The IRE will be composed of two separate facilities

1. Target Facility:
demonstrate target injection and tracking in an IFE chamber environment

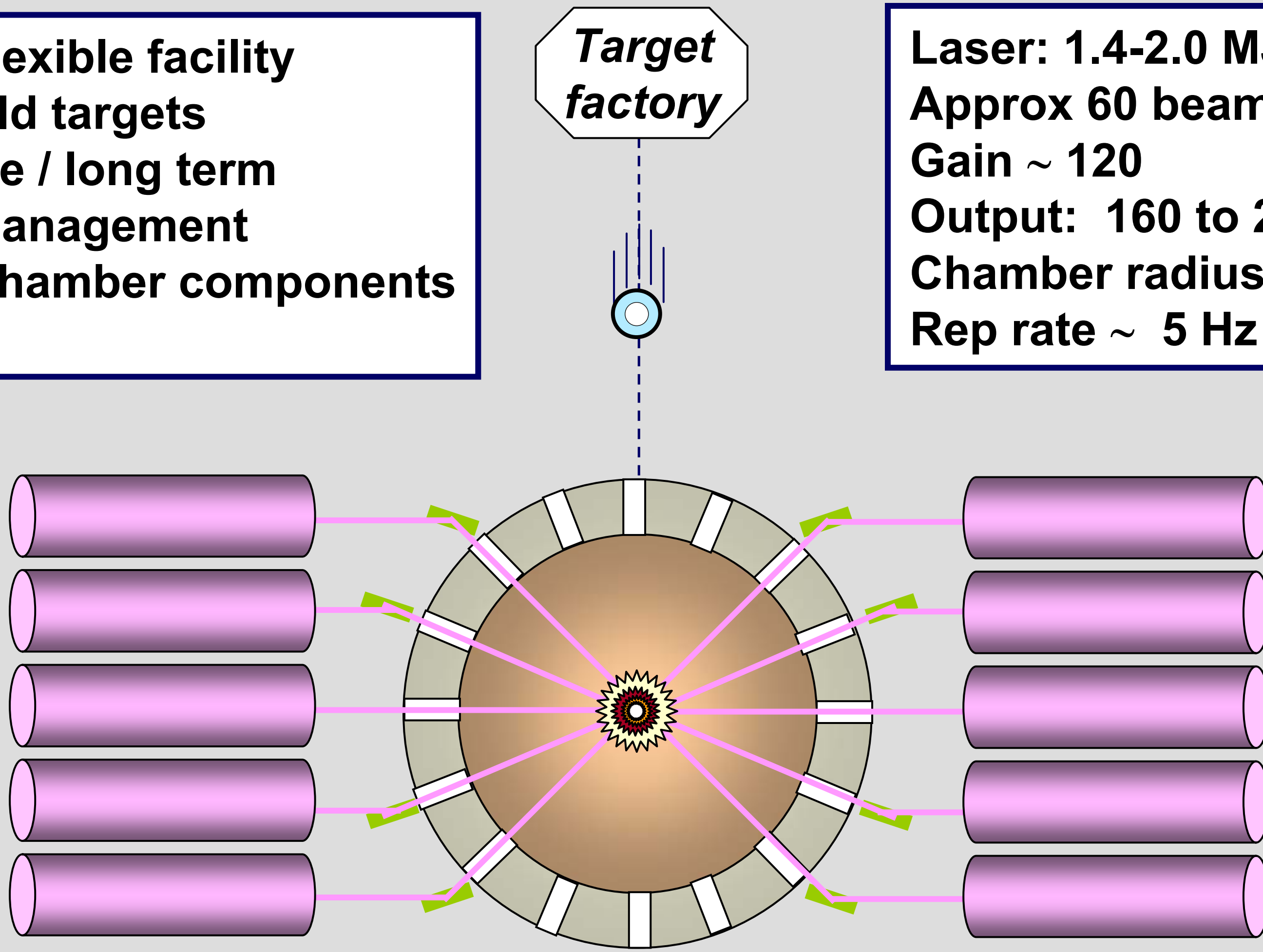
2. Laser Facility:
Full energy laser beam line
Steer beam to hit injected target
Test materials in “mini’ chamber
Evaluate chamber clearing models
Test final optics





The Engineering Test Facility

Modular, flexible facility
Fusion yield targets
Burst mode / long term
Thermal management
Evaluate chamber components

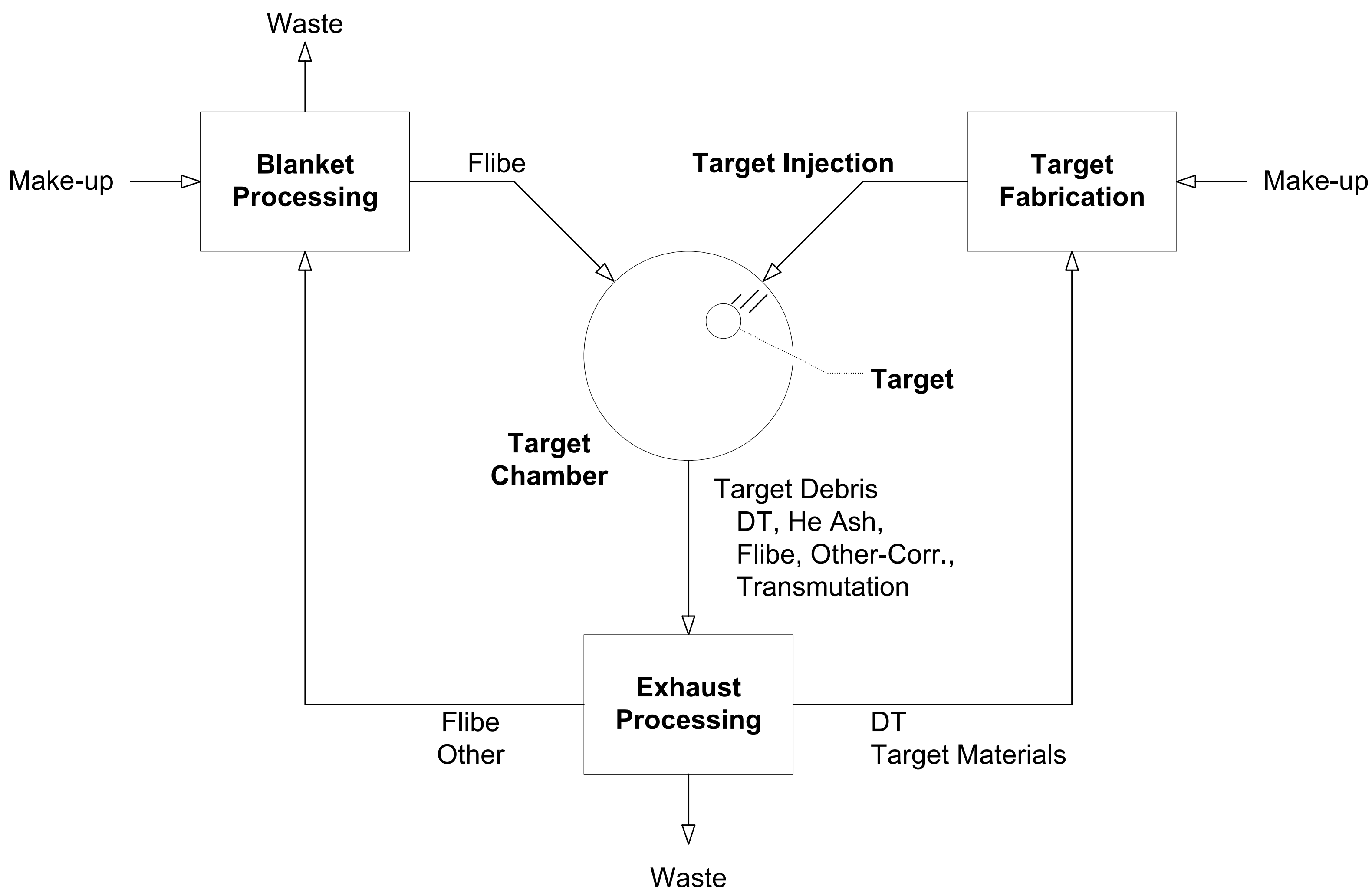


Laser: 1.4-2.0 MJ
Approx 60 beams
Gain ~ 120
Output: 160 to 240 MJ
Chamber radius ~ 4-6 m
Rep rate ~ 5 Hz

Many of the systems included in the ITER tritium plant design will also be needed for an IFE machine

- Torus exhaust processing
  - Front-end permeator
  - Impurities detritiation
  - Glow discharge cleaning exhaust processing
  - Process waste detritiation
- Isotope Separation
- Fuel storage and distribution
- Water detritiation
- Atmosphere detritiation
- Analytical facilities
- Tritium extraction from blanket module
- Instrumentation and control

Major material streams for an IFE target chamber



An integrated IFE design must balance sometimes conflicting criteria

System	Key Criteria
Target design	Sufficient yield Survive injection
Target Fabrication	Cost Meet tolerances Sufficient quantities
Target chamber	Compatible materials Chamber clearing
Blanket material	Shielding Cooling Breeding
Chamber exhaust	Separable and recyclable
All systems	Reasonable tritium inventory Safe and environmentally friendly

US/Japan collaboration is beginning to study tritium interactions with IFE-relevant blanket materials at INEEL

- "Flibe" is a mixture of LiF and BeF_2
- Flibe is being considered as a liquid blanket material for MFE and IFE
- Collaboration will study the various aspects of Flibe
  - Handling and purification
  - Sampling and analysis
  - REDOX control
  - Long-term compatibility
  - Interaction with tritium
  - Safety experiments

Typical "pot" experiment

Summary

- The US is actively studying inertial confinement fusion (ICF)
  - Present experiments are at Omega
  - NIF is under construction
- In recent year's the US has begun to place greater emphasis on inertial fusion energy (IFE)
  - Heavy ion driver
  - High repetition rate laser
  - Other drivers
- There are a number of tritium issues associated with ICF and IFE
  - Fabrication and handling of DT targets
  - Behavior of DT (e.g. DT ice layering and thermal shock)
  - Compatibility with materials (e.g. Flibe and target materials)
  - Separating a chamber exhaust consisting of DT, blanket material and target debris
  - Construction and operation of efficient tritium cleanup systems